Journal of Clinical Densitometry: Assessment & Management of Musculoskeletal Health, vol. ■, no. ■, 1–7, 2016

1094-6950/■:1–7/$36.00
http://dx.doi.org/10.1016/j.jocd.2016.01.005

Original Article

The Relationship of Physical Activity and Anthropometric and Physiological Characteristics to Bone Mineral Density in Postmenopausal Women

Hamid Arazi,[*,1] *Ehsan Eghbali,*[1] *Tahmineh Saeedi,*[1] *and Roya Moghadam*[2]

[1]*Department of Exercise Physiology, Faculty of Sport Sciences, University of Guilan, Rasht, Iran; and* [2]*Orthopaedic Surgeon, Poorsina Hospital, Rasht, Iran*

Abstract

The aim of this study is to investigate the relationship of physical activity and anthropometric and physiological characteristics to bone mineral density (BMD) in postmenopausal women. Ninety-seven postmenopausal women with an average age of 50.71 ± 6.86 yr were selected to participate in this study. After completing consent forms and the questionnaire on physical activity, the amounts of calcium and 25-hydroxyvitamin D levels in participants' blood were measured by blood tests. The BMDs of the subjects in the lumbar spine (L2–L4) and hip were measured by dual-energy X-ray absorptiometry device and the results were recorded. Also, anthropometric characteristics including height, weight, body fat percentage, body mass index, waist-to-hip ratio (WHR), digit ratio (2D:4D), skeletal muscle mass index, hand and calf circumferences and physiological parameters, including handgrip strength, quadriceps isotonic extension strength and balance of the subjects, were measured. The results showed that the 2D:4D ratio and skeletal muscle mass index had a significantly positive relationship with BMD of the lumbar spine ($p \leq 0.05$) and the hip ($p \leq 0.05$). Also, there was a negative relationship between the BMD of lumbar spine and hip and WHR ($p \leq 0.05$). Moreover, there was a positive relationship between the calf circumferences and lumbar spine BMD ($p \leq 0.05$). Contrary to this, there was no significant relationship between the calf circumference and the hip BMD, and between hand circumference with lumbar spine and hip BMD ($p > 0.05$). Results of physiological indices showed a significant positive relationship between physical activity, handgrip strength, quadriceps isotonic extension strength, standing on 1 foot with the lumbar spine and hip BMD ($p \leq 0.05$). But the relationship was not observed between BMD and the ability to squat down on the floor ($p > 0.05$).

Based on these results, it seemed that we can use some physiological and anthropometric indices that are important determinants of BMD and risk of osteoporosis in postmenopausal women.

Key Words: 2D:4D; bone mineral density; handgrip strength; physical activity; postmenopausal women.

Received 10/23/15; Revised 01/12/16; Accepted 01/13/16.
*Address correspondence to: Hamid Arazi, PhD, Department of Exercise Physiology, Faculty of Sport Sciences, University of Guilan, P.O. Box 41635-1438, Rasht, Iran. E-mail: hamidarazi@yahoo.com

Introduction

Aging is related to decreased functions of muscles and bones, leading to osteoporosis and sarcopenia *(1)*. Osteoporosis is a silent disease that is characterized by loss of bone density. This disease has been proposed as a growing health problem in the world and in Asian countries due to older populations (2). Osteoporosis is a systemic skeletal disease identified by reduction of bone density and destruction of bone tissue and increase of bone fragility (1), and experts classified it into 2 types: primary (intrinsic bone disorder) and secondary (caused by another disease or side effects of treatment). Primary bone disorders may be related to immobility (inability to move) (3). The World Health Organization (WHO) defines osteopenia and osteoporosis based on bone mass: osteopenia is bone mass less than −1 and more than −2.5 standard deviations in relation to the mean bone mass of young adults, and osteoporosis is bone mass less than −2.5 standard deviations in relation to the mean bone mass of young adults (4).

The aging process, along with changes in body composition, leads to bone and muscle loss. Progressive loss of muscle mass occurs approximately at the age of 40 (5). After menopause, muscle mass is reduced by 3% per year, and between the ages of 40 and 80 yr, 30%–50% of muscle loss occurs (5).

The aim of the present study was to evaluate the relationship of physical activity and anthropometric and physiological characteristics to bone mineral density (BMD) in postmenopausal women. In the past decades, several studies have been conducted in this field and mixed results were obtained from different societies, but this relationship has not been studied in Iranian women. Also in the present study, the researcher wants to examine the relationship of 2D:4D ratio, waist-to-hip ratio (WHR), and calf circumference to BMD in postmenopausal women for the first time.

Materials and Methods

This was a descriptive study and the University Ethics Committee approved the terms of the project. Participants declared their preparation on a voluntary basis, after announcements in medical offices and associated laboratories. The participants in the study who suffered from hypothyroidism or hyperthyroidism, parathyroid and adrenal glands, diabetes, established rheumatologic diseases; had a history of drugs affecting BMD (corticosteroids); had advanced heart disease or any type of cancer; had an implant in the body, fractures in the previous months, complete bed rest for 3 consecutive months; or those who were smoking and consumed alcohol were excluded from the study (6,7). In the first session, the level of physical activity was measured using the Beck questionnaire of physical activity (8). Also, participants filled in consent forms, and general health information on menopause and age of menopause onset were required from the subjects. In addition, blood levels of calcium and 25 OHD were measured and people who had normal blood levels participated in the study. After explaining the procedures and working methods, measurements were carried out. First, the anthropometric indices and then physiological parameters were measured. All measurements were performed at 8–12 AM. In a separate meeting, the BMD of participants was measured and was classified according to WHO classification in 3 groups: healthy, osteopenic, and osteoporotic.

Anthropometric Measurements

Heights and weights of the subjects were measured and then body mass index was calculated using the formula of weight divided by the square of height. Also, for the measurement of WHR, first, the waist and the hip circumferences were measured in a standing position, then by dividing the waist-to-hip circumference, WHR was calculated. For measuring calf circumference, a tape measure was used on the right leg. While the subject was standing, a tape was placed around the largest part of the leg circumference and the maximum circumference of leg was recorded (subcutaneous tissue was not compressed) (9). To measure the hand circumference, a tape was used. The widest part of the palm was measured by using tape and wrapping it around the palms (10).

In addition to measure skeletal muscle mass (SM), the skeletal muscle mass index (SMI) was used. To calculate the SMI, first SM was calculated using the following formula (11):

$$\mathrm{SM} = 0.244 \times \mathrm{weight} + 7.80 \times \mathrm{height} + 6.6 \times \mathrm{sex} - 0.098 \times \mathrm{age} + \mathrm{race} - 3.3$$

$$\left(R^2 = 0.86,\ p < 0.0001,\ \mathrm{SEE} = 2.8\ \mathrm{kg}\right)$$

where sex = 0 for female and 1 for male, race = −1.2 for Asian, 1.4 for African American, and 0 for white and Hispanic.

Then SMI was calculated by dividing the SM (kilogram) by squared height (square meter) (11).

The digit ratio of the right hand was calculated according to the method recommended by Manning et al (12). The lengths of the index and ring fingers were measured on the palmar surface of the hand from the basal crease proximal to the palm to the tip of the finger using digital calipers (Mitutoyo, model digimatic caliper 500-151-20, Mitutoyo, China) with the accuracy of 0.01 mm. After measuring the length of the fingers, again measurements were repeated and the mean of the 2 measurements was recorded. The 2D:4D ratio was obtained by dividing the length of the index finger by the length of the ring finger (12).

Physiological Measurements

Handgrip Strength (HGS)

HGS was measured using a digital dynamometer (Seahan, model SH5003, Seahan Co, South Korea). The participants performed the test in a sitting position on a chair, with their elbow extended to 180° along the vertical axis and their wrists in slight extension. This test was repeated 3 times with 15 s between trials, and the mean value was recorded in kilogram (right hand was dominant in people and the reliability $r = 0.96$ for the present device was recognized as high) (13).

Quadriceps Isotonic Extension Strength

Maximal leg extension was measured by sitting in a leg extensor bench. First, after 5 min of warm-up and familiarization with the fitness machine, testing was performed. By using multiple repetitions and the following formula, the maximal leg extension was calculated *(14)*:

$$\text{One-repetition maximum (1RM)} = \frac{\text{Load (kg)}}{1.0278 - [0.0278 \times \text{maximum amount of repetitions}]}$$

Standing on 1 Foot (SOOF)

The subjects were asked to perform a 1-leg stand (dominant foot) for 30 s with eyes open. At this time, the weight-bearing foot was not allowed to move and the hands should be on the sides of the waist. The participants tried twice and the maximum record was recorded in seconds (the reliability of the tests is 0.85) *(15)*.

Squat Down on the Floor

In this test, the participants were asked to squat down vertically in a stable position and to touch the ground with a finger, and then to rise up again. The test results were recorded by yes/no (the test reliability was reported to be moderate) *(16)*.

Blood Measurements

Fasting blood samples were taken from a forearm vein between 8:00 AM and 10:00 AM. The determination of 25-hydroxyvitamin D was tested by enzyme-linked immunosorbent assay method with sensitivity of 5 nm/L (Stat Fax 2100, Awareness Technology, Palm City, FL). The blood level of calcium was determined with the AutoAnalyzer RA-100 (Bayer-Technicon, Leverkuser, Germany). All measurements were taken in winter and the normal levels of 25-hydroxyvitamin D 25–80 ng/mL and calcium 8.50–10.50 mg/dL were considered.

Measurement of BMD

BMD was measured at 2 areas of the lumbar spine (L2–L4) and hip by dual-energy X-ray absorptiometry device (QDR 4500 W, Hologic Inc., Bedford, MA) and, based on the classification of the WHO, was placed in 3 groups: healthy, osteopenic, and osteoporotic *(4)*.

Statistical Analysis

By using the data related to the variables, the mean and standard deviation of scores of participants were calculated by descriptive statistics. The data were found normal by Kolmogorov–Smirnov test, and the parametric test of Pearson relationship coefficient was used to determine the association between mentioned variables. To compare the results between the healthy, osteopenic, and osteoporotic groups, one-way analysis of variance was used. After it was confirmed that there is a significant difference between the means, the Bonferroni post hoc test was used. Statistical operation of the present study was performed using SPSS 20 software and Excel 2010 (IBM, Armonk, NY and Microsoft, Redmond, WA). The significance level was considered as $p \leq 0.05$ at all stages.

Results

A total of 97 postmenopausal women with an average age of 50.71 ± 6.86 yr participated in the present study. The characteristics of anthropometric, physical tests and BMD measurements of the study population at baseline are shown in Table 1.

The WHR, SMI, and 2D:4D were associated with lumbar spine BMD ($r = -0.26, p = 0.01; r = 0.32, p = 0.001; r = 0.53, p < 0.001$; respectively) and the hip regions ($r = -0.25, p = 0.01; r = 0.30, p = 0.003; r = 0.51, p < 0.001$; respectively). The calf circumference was associated with lumbar spine BMD ($r = 0.20, p = 0.04$). There was no association observed between the calf circumference and the hip BMD

Table 1
Characteristics of the Study Population

Characteristic	Mean ± SD
Age (yr)	50.71 ± 6.86
Age when menopause started (yr)	47.53 ± 2.17
Height (cm)	159.39 ± 5.62
Weight (kg)	67.50 ± 12.35
Body fat (%)	38.75 ± 6.06
BMI (kg/m^2)	26.62 ± 4.88
WHR	0.81 ± 0.07
SMI (kg/m^2)	7.72 ± 1.14
2D:4D	0.98 ± 0.05
Calf circumference (cm)	34 ± 6.18
Hand circumference (cm)	19.67 ± 1.47
HGS right (kg)	23.07 ± 5.55
HGS left (kg)	19.55 ± 4.86
Leg extension strength (kg)	21.09 ± 5.88
Standing on 1 foot (s)	26.52 ± 6.01
Ability to squat down on the floor (number [%])	72.97
Lumbar spine (L2–L4) BMD (*T*-score)	–1.52 ± 1.28
Hip BMD (*T*-score)	–1.50 ± 1.33
Physical activity level	6.01 ± 2.13
Calcium (mg/dL)	9.2 ± 0.27
25OHD (ng/mL)	32 ± 6.35

Abbr: 25OHD, 25-hydroxyvitamin D; BMD, bone mineral density; BMI, body mass index; HGS, handgrip strength; SD, standard deviation; SMI, skeletal muscle mass index; WHR, waist-to-hip ratio.

Table 2
Associations of Physical Activity and Anthropometric and Physiological Characteristics With BMD (*T*-Score)

	Lumbar spine BMD		Hip BMD	
Variable	*r*	*p*	*r*	*p*
WHR	−0.26	0.01*	−0.25	0.01*
SMI	0.32	0.001*	0.30	0.003*
2D:4D	0.53	<0.001*	0.51	<0.001*
Calf circumference	0.20	0.04*	0.12	0.24
Hand circumference	0.09	0.38	0.11	0.26
Physical activity level	0.86	<0.001*	0.83	<0.001*
HGS right	0.65	<0.001*	0.63	<0.001*
HGS left	0.43	<0.001*	0.45	<0.001*
Leg extension strength	0.64	<0.001*	0.60	<0.001*
Standing on 1 foot (s)	0.30	0.003*	0.24	0.01*
Ability to squat down on the floor (yes/no)	−0.04	0.68	−0.11	0.27

Abbr: BMD, bone mineral density; HGS, handgrip strength; SMI, skeletal muscle mass index; WHR, waist-to-hip ratio.
*Significance at the ≤0.05 level.

($p > 0.05$). Also, the hand circumference was not associated with lumbar spine BMD and the hip BMD ($p > 0.05$) (Table 2).

The physical activity, HGS (right and left hands), leg extension strength, and SOOF tests were associated with lumbar spine BMD ($r = 0.86, p < 0.001$; $r = 0.65, p < 0.001$; $r = 0.43, p < 0.001$; $r = 0.64, p < 0.001$; $r = 0.30, p = 0.003$; respectively) and the hip regions ($r = 0.83, p < 0.001$; $r = 0.63$, $p < 0.001$; $r = 0.45$, $p < 0.001$; $r = 0.60$, $p < 0.001$; $r = 0.24$, $p = 0.01$; respectively). There was no independent association observed between the ability to squat down on the floor and BMD ($p > 0.05$) (Table 2).

The subjects were divided into normal, osteopenic, and osteoporotic groups according to the *T*-score of the lumbar spine and hip BMD (WHO classification). Osteoporotic women, according to lumbar spine and hip BMD, performed significantly worse in HGS, leg extension strength, and SOOF ($p < 0.05$) (Table 3). Also, significant differences among groups in some anthropometric characteristics were observed (Table 3).

Discussion

The aim of the present study was to investigate the relationship between physical activity and anthropometric and physiological characteristics with BMD in postmenopausal women. The results showed that physical activity and some anthropometric (WHR, SMI, 2D:4D, and calf circumference) and physiological characteristics (HGS, leg extension, and SOOF) were related to BMD in postmenopausal women.

The results showed that there was a positive relationship between the bone density of the spine and hip with 2D:4D in postmenopausal women. Researchers have shown that the 2D:4D ratio is determined by the balance between androgens to estrogens. The androgen receptor and the estrogen receptor are more active on the fourth finger in comparison to the second finger. Inactivation of the androgen receptor reduces the growth rate of the fourth finger and increases the 2D:4D ratio, while inactivation of estrogen receptor increases the growth rate of the fourth finger and consequently leads to the reduction of the 2D:4D ratio *(17)*. So we can say that the 2D:4D ratio reflects the level of androgen and estrogen in circulation.

The transcript level in 4D relative to 2D is determined by 19 genes *(17)*. Several genes in skeletal and other tissues of these genes are regulated by steroids; genetic studies indicated that Runx2, Sox9, lgfbp2/5, Fgfr2, Bmp6, Ihh, and Wnt5a have an important role in the development of fingers. For example, it has been shown that Wnt5a regulates the speed of increase of chondrocytes and maturation in long bones. The results showed that androgen is the negative regulator expression of Wnt5a in ratio of fingers and when Wnt5a is positively regulated on the fourth finger after conflict with androgen, this may lead to the reduced cell proliferation and shortened fourth finger size and an increase in 2D:4D ratio, which increases the female ratio development in the fingers *(17)*. Also, studies have shown that bone loss related to aging is because of estrogen reduction *(2)*.

The obtained results demonstrated that there was a negative relationship between WHR and lumbar spine and hip BMD. As mentioned, women with low WHR had lower testosterone and high estrogen, while women with high WHR had high testosterone and lower estrogen *(18)*. Menopause is related to a reduction in hip circumference and abdominal fat. The difference between the metabolism of gluteal–femoral fat cells and abdominal fat cells, which are responsible for the distribution of body fat in young women, disappeared after menopause. Also, the reduction of progesterone amount can have a role before menopause (when

Table 3
Anthropometric Characteristics and Physical Tests in Women With Normal, Osteopenic, and Osteoporotic Lumbar Spine and Hip According to WHO Classification

	Lumbar spine (L2–L4) BMD		Hip BMD	
Variable	Normal (33)	vs osteopenic (36) vs osteoporotic (28)	Normal (29)	vs osteopenic (44) vs osteoporotic (24)
WHR	0.78	0.83 ($p = 0.009$) 0.82 ($p = 0.09$)	0.77	0.82 ($p = 0.02$) 0.82 ($p = 0.08$)
SMI	8.29	7.51 ($p = 0.01$) 7.38 ($p = 0.006$)	8.24	7.59 ($p = 0.05$) 7.39 ($p = 0.02$)
2D:4D	1.02	0.99 ($p = 0.01$) 0.94 ($p < 0.001$)	1.03	0.98 ($p = 0.001$) 0.95 ($p < 0.001$)
Calf circumference	36.76	32.69 ($p = 0.01$) 32.71 ($p = 0.03$)	35.57	32.97 ($p = 0.20$) 34.16 ($p = 0.69$)
Hand circumference	19.99	19.23 ($p = 0.09$) 19.91 ($p = 0.97$)	20.14	19.35 ($p = 0.07$) 19.77 ($p = 0.63$)
Physical activity level	8.83	4.83 ($p < 0.001$) 4.50 ($p < 0.001$)	8.92	5.18 ($p < 0.001$) 4.37 ($p < 0.001$)
HGS right	27.94	21.81 ($p < 0.001$) 19.48 ($p < 0.001$)	28.48	22.09 ($p < 0.001$) 19.01 ($p < 0.001$)
HGS left	22.48	18.45 ($p = 0.001$) 17.82 ($p < 0.001$)	23.49	18.76 ($p < 0.001$) 16.73 ($p < 0.001$)
Leg extension strength	26.51	19.51 ($p < 0.001$) 17.30 ($p < 0.001$)	26.38	20.13 ($p < 0.001$) 17.10 ($p < 0.001$)
Standing on 1 foot (s)	29.38	25.75 ($p = 0.03$) 24.44 ($p = 0.004$)	29.69	25.18 ($p = 0.006$) 25.54 ($p = 0.03$)
Ability to squat down on the floor (yes/no)	1.23	1.22 ($p = 0.91$) 1.14 ($p = 0.67$)	1.07	1.25 ($p = 0.19$) 1.25 ($p = 0.28$)

Abbr: BMD, bone mineral density; HGS, handgrip strength; SMI, skeletal muscle mass index; WHR, waist-to-hip ratio.

this hormone helps fat accumulation in hip and thigh) *(19)*. Estrogen directly reduces WHR by increasing fat deposits in the hip and thigh and increasing lipolysis in abdominal fat *(19)*. According to the results of the present research and the relationship of WHR with androgen and estrogen, it seems likely that there is a significant association between WHR and bone density.

In addition, in the present study, the relationship between anthropometric variables (the calf circumference and hand circumference) and BMD of lumbar spine and hip was investigated. The results showed a positive relationship between the calf circumference and lumbar spine BMD, but there was no significant relationship between the calf circumference and hip BMD and between hand circumference and BMD in both areas.

People with osteoporosis have greater postural imbalance *(20)*. The study of Landi et al *(21)* showed that the calf circumference is directly related to the balance and better performance of older persons, and it can be said that the people who had more calf circumference probably had a better balance and had a lower rate of falls and fractures. Moreover, the calf circumference is considered as the most sensitive anthropometric measurement to assess muscle mass in the elderly by the WHO *(22)*. Research suggested that it is a proper evaluation index for muscle mass in the elderly *(23)*. Regarding the relationship between muscle mass and BMD, it seems that possibly there is a relationship between the calf circumference and BMD. In the present study, there was only a significant relationship observed between the BMD of the lumbar spine and the calf circumference.

According to researchers, there is a strong positive relationship between the hand circumference and HGS in men and women *(10,13)*. The results of studies showed a positive association between BMD and the HGS. Accordingly, it is hypothesized that perhaps there was a significant relationship between the hand circumference and BMD, and possibly hand circumference can be used as an anthropometric indicator to predict BMD. The results of the present study showed no significant relationship, which is contrary to this hypothesis. In this regard, there is a study conducted by Kaya et al *(24)*, which showed no relationship between hand circumference and BMD in men and women. Very little research has been done in this field and its mechanism is not clear.

The results of the present study showed a significant positive relationship between, upper body and lower body muscle strength and SMI with BMD. In this regard, a study conducted by Kärkkäinen et al (25) showed that the HGS and leg extension strength are associated with BMD in postmenopausal women. Research of Kärkkäinen et al (6) has shown that HGS is related to the lumbar spine and hip BMD, but the leg extension strength is not related to the BMD of any area.

The research results of Chan et al (26) and Marin et al (7) indicated that there is a significant relationship between the HGS and the BMD of the lumbar spine, the femoral neck and the whole body in women.

In contrast to these results, Khalil et al (27) reported that there is no relationship between the HGS and leg extension strength and the lumbar spine BMD in older men. They suggested that environmental factors have a significant impact on bone strength (27). The research of Kaya et al (24) demonstrated that there was a relationship between the HGS and the BMD in hands of men, but there was no such relationship in postmenopausal women. They linked the reason for the lack of a significant relationship in women to their status of estrogen levels or physical activity (mainly limited to leisure activities) (24).

In the present research, the results showed that the ability to stand on 1 foot had a positive association with spine and hip BMD, but there was no significant relationship between the ability to squat down on the floor and BMD. The study done by Kärkkäinen et al (6) showed there is a relationship between SOOF with lumbar spine and hip BMD, and the ability to squat down on the floor is related to hip BMD. In addition, it was found that there is no relationship between the chair rising test and the SOOF test with eyes closed for 10 s and bone density in any area. The research of Kärkkäinen et al (25) showed that SOOF for 10 s in postmenopausal women is related to BMD. Balance control, is the intrinsic capacity of an individual to maintain the body's center of gravity according to the definition of the limits of stability. Elderly women with osteoporosis have less balance and risk of falling. Reduction of estrogen in women after menopause is related to decrease in muscle strength and imbalance (20).

But Abreu et al (28), Silva et al (29), and Cangussu et al (30) reported that osteoporosis does not worsen balance situation. The difference in results may be caused by other relevant factors, particularly performance reduction, which is related to aging and may be worse in women with osteoporosis (28–30).

Physical activity probably can reduce the rate of bone loss and bone weakness caused by aging. However, it is known that estrogen response to mechanical loads is decreased with increasing age. It seems that the effect of exercise on BMD is related to the osteocyte activities, which leads to the balance between resorption and formation. Studies have shown that, to create a positive impact on bone density, the created mechanical load should provide adequate pressure and should be large enough (31). It has been shown that mechanical loads of predictive marker expression (bone morphogenetic protein-2, type I collagen, and alkaline phosphatase) stimulate different shapes of osteoblasts in MC3T3-E1 cells (32).

According to the findings, it seems that some anthropometric variables such as the 2D:4D ratio had a relatively good relationship with BMD. Also, physiological variables such as the HGS, leg extension, and physical activity had a strong relationship with bone mass. Accordingly, these variables possibly can be used in the early stages of bone density measurements because they are important determinants of bone mass in postmenopausal women. Some of the variables used in this research are used for the first time and there is a need for further examinations of these variables in different communities and geographic areas.

Acknowledgments

The authors hereby declare their gratitude to all those who participated as subjects in this study.

References

1. Tagliaferri C, Wittrant Y, Davicco MJ, et al. 2015 Muscle and bone, two interconnected tissues. Ageing Res Rev 21:55–70.
2. El Hage R, Baddoura R. 2012 Anthropometric predictors of geometric indices of hip bone strength in a group of Lebanese postmenopausal women. J Clin Densitom 15(2):191–197.
3. Titmuss AT, Biggin A, Korula S, et al. 2015 Diagnosis and management of osteoporosis in children. Curr Pediatr Rep 3(2):187–199.
4. El Hage R, Theunynck D, Jacob C, et al. 2012 Anthropometric predictors of bone mineral density in healthy Lebanese subjects aged 13 to 25 years. Sci Sports 27(4):241–245.
5. Park JH, Park KH, Cho S, et al. 2013 Concomitant increase in muscle strength and bone mineral density with decreasing IL-6 levels after combination therapy with alendronate and calcitriol in postmenopausal women. Menopause 20(7):747–753.
6. Kärkkäinen M, Rikkonen T, Kröger H, et al. 2009 Physical tests for patient selection for bone mineral density measurements in postmenopausal women. Bone 44(4):660–665.
7. Marin RV, Pedrosa MAC, Moreira-Pfrimer LDF, et al. 2010 Association between lean mass and handgrip strength with bone mineral density in physically active postmenopausal women. J Clin Densitom 13(1):96–101.
8. Baecke JA, Burema J, Frijters JE. 1982 A short questionnaire for the measurement of habitual physical activity in epidemiological studies. Am J Clin Nutr 36(5):936–942.
9. Bastiaanse LP, Hilgenkamp TI, Echteld MA, et al. 2012 Prevalence and associated factors of sarcopenia in older adults with intellectual disabilities. Res Dev Disabil 33(6):2004–2012.
10. Hemberal M, Doreswamy V, Rajkumar S. 2014 Study of correlation between hand circumference and maximum grip strength (MGS). Natl J Physiol Pharm Pharmacol 4(3):195–197.
11. Lee RC, Wang Z, Heo M, et al. 2000 Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. Am J Clin Nutr 72(3):796–803.

12. Manning JT, Scutt D, Wilson J, et al. 1998 The ratio of 2nd to 4th digit length: a predictor of sperm numbers and concentrations of testosterone, luteinizing hormone and oestrogen. Hum Reprod 13(11):3000–3004.
13. Li K, Hewson DJ, Duchêne J, et al. 2010 Predicting maximal grip strength using hand circumference. Man Ther 15(6):579–585.
14. Brzycki M. 1993 Strength testing-predicting a one-rep max from reps-to-fatigue. J Phys Educ Recreat Dance 64(1):88–90.
15. Giorgetti MM, Harris BA, Jette A. 1998 Reliability of clinical balance outcome measures in the elderly. Physiother Res Int 3(4):274–283.
16. Alaranta H, Hurri H, Heliövaara M, et al. 1994 Non-dynamometric trunk performance tests: reliability and normative data. Scand J Rehabil Med 26(4):211–215.
17. Zheng Z, Cohn MJ. 2011 Developmental basis of sexually dimorphic digit ratios. PNAS 108(39):16289–16294.
18. Manning JT, Barley L, Walton J, et al. 2000 The 2nd:4th digit ratio, sexual dimorphism, population differences, and reproductive success: evidence for sexually antagonistic genes? Evol Hum Behav 21(3):163–183.
19. Cashdan E. 2008 Waist-to-hip ratio across cultures: trade-offs between androgen-and estrogen-dependent traits. Curr Anthropol 49(6):1099–1107.
20. Brech GC, Plapler PG, de Souza Meirelles E, et al. 2013 Evaluation of the association between osteoporosis and postural balance in postmenopausal women. Gait Posture 38(2):321–325.
21. Landi F, Onder G, Russo A, et al. 2014 Calf circumference, frailty and physical performance among older adults living in the community. Clin Nutr 33(3):539–544.
22. WHO. 1994 Physical status. The use and interpretation of anthropometry. Report of a WHO Expert Committee. WHO Tech Rep Ser 845.
23. Rolland Y, Lauwers-Cances V, Cournot M, et al. 2003 Calf circumference, and physical function of elderly women: a cross-sectional study. J Am Geriatr Soc 51(8):1120–1124.
24. Kaya A, Ozgocmen S, Ardicoglu O, et al. 2005 Relationship between grip strength and hand bone mineral density in healthy adults. Arch Med Res 36(5):603–606.
25. Kärkkäinen M, Rikkonen T, Kröger H, et al. 2008 Association between functional capacity tests and fractures: an eight-year prospective population-based cohort study. Osteoporos Int 19(8):1203–1210.
26. Chan DCC, Lee WTK, Lo DHS, et al. 2008 Relationship between grip strength and bone mineral density in healthy Hong Kong adolescents. Osteoporos Int 19(10):1485–1495.
27. Khalil N, Faulkner KA, Greenspan SL, et al. 2014 Associations between bone mineral density, grip strength, and lead body burden in older men. J Am Geriatr Soc 62(1):141–146.
28. Abreu DCC, Trevisan DC, Reis JG, et al. 2009 Body balance evaluation in osteoporotic elderly women. Arch Osteoporos 4(1–2):25–29.
29. Silva RB, Costa-Paiva L, Oshima MM, et al. 2009 Frequency of falls and association with stabilometric parameters of balance in postmenopausal women with and without osteoporosis. Rev Bras Ginecol Obstet 31(10):496–502.
30. Cangussu LM, Nahas-Neto J, Nahas EAP, et al. 2012 Evaluation of postural balance in postmenopausal women and its relationship with bone mineral density-a cross sectional study. BMC Musculoskelet Disord 13(1):2.
31. Marques EA, Mota J, Carvalho J. 2012 Exercise effects on bone mineral density in older adults: a meta-analysis of randomized controlled trials. Age (Omaha) 34(6):1493–1515.
32. Lu HF, Mai ZH, Xu Y, et al. 2012 Mechanical loading induced expression of bone morphogenetic protein-2, alkaline phosphatase activity, and collagen synthesis in osteoblastic MC3T3-E1 cells. Chin Med J 125(22):4093–4097.